Antenna IQ Brainteaser

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Introduction

Antenna theory can sometimes be a tad dry. For the typical amateur radio operator who is not a practicing engineer in the field of antenna engineering, the association of practice to theory can become a bit strained leading to incorrect assumptions and generalizations that creep into the articles, vernacular, and assertions of our hobby.

To this end, I offer this Antenna IQ series in a fun, brainteaser format. The questions are constructed so that you can easily re-use the brainteaser during your next QSO or club meeting. They are guaranteed to spark plenty of disbelief, debate, and ultimately enlightenment. The number of Antenna IQ Brainteasers produced will be determined by your feedback. I hope you enjoy them.

Consider the Following

Bill has recently upgraded to General class and he is anxious to get on the HF bands. He has managed to collect a nice all solid state HF transceiver, a good quality antenna tuner, 100 feet of Belden 9913, a balun, 150 feet of antenna wire, and all the necessary accessories to put up an antenna.

At a Saturday morning breakfast, Bill's Elmer, Al asked how Bill's station plans are going. Bill was excited to report on his research and ideas. "I have the space for a full size 80 meter dipole and can get it about 60 feet in the air using some of the large trees in my yard so I thought I would start there. I plan to cut it for the middle of the band and use the antenna tuner to match the antenna. The SWR without the tuner should be no more than 5:1 at the band edges so it should work out well for both CW and phone," blurts Bill.

"Hold on just a minute," interrupts Al. "I have put up and tested a lot of antennas in my 23 years as a ham. An antenna with a 5:1 SWR is just not acceptable. The coax and reflected power losses will make that antenna very ineffective. Your coax may radiate as well with that high of SWR. Keep the SWR under 2:1 and you can use the tuner from there to keep the transmitter happy."

"I have to admit that some of this is over my head. I thought the tuner would take care of matching the antenna so the SWR wouldn't be a problem," a humbled Bill retorts. "It seemed like the 5:1 SWR would make no real difference on my signal."

Now Answer the Following Question

Who would you side with, Elmer Al or newbie Bill?

[Stop reading here if you don’t want to see the answer just yet.]

Working Out Your Answer

Probably the first or second piece of test equipment a ham radio operator acquires is an SWR meter. We are conditioned early on to pay attention to the SWR of our antennas. As we peruse the antenna ads, almost all of them make some type of assertion regarding SWR. Most of the new breed of antenna analyzers have full SWR reporting capability. Clearly, SWR is an important topic to amateur radio operators. To the average ham radio operator a 5:1 SWR doesn’t sound very good.

While SWR is one parameter that we should know and monitor, it is regularly misunderstood and misapplied. Bill has outwitted his Elmer, Al. All of Al’s assertions regarding the antenna Bill has planned are false. Read on…

The Detailed Answer

Al was worried about the “reflected power losses” due to the 5:1 SWR. When an antenna is “matched” using an antenna tuner as Bill has planned, the power that has been reflected from the antenna toward the antenna tuner is returned to the antenna – not lost somewhere. Al was completely wrong on this point. The antenna tuner performs what is called a conjugate match.

Let’s look at a conjugate match from a non-technical perspective (engineers - please forgive the minor foibles of this analogy). Think of the transmitter handing off 100 watts to the antenna tuner. The job of the antenna tuner is to not give any of it back to the transmitter (show the transmitter a 1:1 SWR) and to deliver the full 100 watts to the antenna. At a 5:1 SWR, the antenna will always consume about 56% of any power given to it and it will always return the remaining 44% to the antenna tuner.

Some people point to the 44% returned power and call it lost power, like Al seems to think. But here is the important bit – the antenna tuner says “No problem, I will just send it back to the antenna again!” The first time, the tuner forwards 100 watts and gets 44 watts back from the antenna. It then forwards the 44 watts and gets back 20, it forwards 20 and gets back 9, and so on. This goes on until finally the full 100 watts is delivered to the antenna and nothing is returned. At a 5:1 SWR, by the time this exchange has happened 15 times, more than 99.999% of the power has been delivered to the antenna. If we add all the power exchanges the tuner has handled to make this happen, it is 180 watts. This is called the *Incident Power*. If we put a directional wattmeter right at the tuner on the antenna side, it would actually show 180 watts. But so far this analogy has ignored the coax, so don’t stop here.

Elmer Al was also worried about “coax losses”. We all know that coax has some loss. Bill chose 9913 coax so at 80 meters his 100 foot length of coax will have a 0.25 dB loss. This means that any signal passing in either direction through the coax will have about 6% of it extracted, mainly as heat.

Let's now look at the influence this coax loss into our analogy. All the actors stay the same but there is now a middle man between the antenna tuner and the antenna – the coax. No power can go in either direction without the middle man collecting his 6% "cut" of the transaction. So when the tuner passes the 100 watts to the antenna, the middle man take his 6% cut, pocketing 6 watts, and sends the remaining 94 watts on to the antenna. The antenna will still return 44% of whatever it gets so it returns 41 watts. But there is the middle man again so he takes his 6% cut, pocketing 2 watts, and passing on the remaining 39 watts to the tuner. And so it goes like before but with the middle man accumulating a small horde of watts just for being the go-between.

If we make the middle man account for everything he collected in all of the exchanges, it turns out to be about 13 watts. But of course the middle man is the coax. So the 13 watts is the total power lost in the coax. Since the coax consumed some of the available power, the *Incident Power* is reduced to about 167 watts. Another point to note is that since the coax is consuming power, it will throw off the reading of the antenna SWR if we try to measure it by the tuner. In our example, the SWR would show as 4.3:1 instead of 5:1.

Before we wrap up this analogy, let's look at one more detail about the coax loss. If an antenna has a 1:1 SWR, then it reflects no power – it consumes all of it. In our analogy, the tuner would send the 100 watts to the antenna, the middle man collects his 6%, and the antenna consumes the remaining 94 watts without sending anything back. Did you notice that the middle man only pocketed 6 watts this time? That gives us the ability to say that 6 watts of loss are attributable to normal coax loss that would be there no matter what the SWR and the remaining 7 watts (13 watts -6 watts) are due to the SWR not being 1:1. A meager 7 watts lost for a 5:1 SWR? That is less than 1/10 of an S unit difference - pure decimal dust!

The *Incident Power* described earlier will always be greater than the transmitter power when the antenna SWR is not 1:1 and we have a tuner performing the conjugate match. As a result, we should always check the maximum voltage developed to make certain we are still within the ratings of the coax. The 9913 coax Bill chose for his project has a maximum voltage rating of 300 volts RMS. If we calculate the voltage of the *Incident Power* at 50 ohms, it is 158 volts so we are well within the coax ratings.

Table 1 is a handy chart showing the effect of various SWRs for Bill's 80 meter station.

SWR at Antenna	Additional dB Cable Loss Due to SWR	S Unit Signal Loss Due to SWR	Calculated Voltage at 100 watts (50 ohms)	SWR at Tuner
1:1	-	-	70.7	1:1
2:1	0.06	0.01	100.0	1.9:1
3:1	0.15	0.03	122.5	2.7:1
4:1	0.26	0.04	141.4	3.6:1
5:1	0.36	0.06	158.1	4.3:1
6:1	0.47	0.08	173.2	5.1:1
7:1	0.57	0.09	187.1	5.8:1
8:1	0.67	0.11	200.0	6.5:1
9:1	0.77	0.13	212.1	7.1:1
10:1	0.86	0.14	223.6	7.7:1
11:1	0.96	0.16	234.5	8.3:1
12:1	1.05	0.18	244.9	8.9:1
13:1	1.14	0.19	255.0	9.4:1

Table 1 - Valid only for 0.25 dB loss cable

Elmer Al also asserted that the SWR could cause the coax to radiate. He might as well have said that high SWR causes aurora borealis, a shift in the magnetic north, and sterility within 5 wavelengths. This is a complete fallacy - a high SWR does not produce antenna currents on the line or cause the line to radiate. Coax radiation is caused by reradiating energy that is coupled into the coax because of asymmetrical positioning of the coax with respect to the antenna or coupling a balanced antenna to an unbalanced coax without the use of a balun. Once again, neither of these conditions are caused by high SWR.

If you would like a handy spreadsheet that can perform all pertinent calculations related to conjugate matching, send me an email at my U.S. call sign at arrl.org. Make sure to put "Antenna IQ Spreadsheet" in the subject line.

Closing Thoughts

SWR is largely a misunderstood and misapplied measurement within the ham radio community. Here are some additional Antenna IQ truths about SWR.

- High SWR can be neutralized with a proper tuner and a low loss feed line for the frequencies involved. There is minimal impact on the remote received signal strength. For example:
    - With reasonable coax, the remote station will not be able to detect ANY difference in the signal due to a 10:1 SWR on any HF band if your tuner can match it. Most dipoles are only 3:1 at band edges.

- Low SWR in itself is not an indication of the quality or efficiency of an antenna system.

- The higher the frequency, the more effect SWR has on signal loss in a coax cable. Pay careful attention at VHF and up frequencies.

- Antenna tuners do introduce a small additional loss that can typically be disregarded. Consult the manual from the manufacturer for expected losses and safe operating guidelines.

- Antenna SWR should only be used to confirm that an antenna is performing as expected when first erected and then to monitor the antenna for any SWR changes (up or down) that may indicate antenna system maintenance is needed.

- The SWR between the transmitter and the tuner should be monitored to ensure the tuner is performing the conjugate match as intended.

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